Appl. No. 09/682,531
Reply to Office action of April 23, 2003

Amendments to the Specification:

Please replace the title beginning on page 1, line 1, and ending on page 1, line 2, with the following amended title:

~~FAULT IDENTIFICATION DUE TO~~ DETECTION OF DEMAGNETIZATION ~~FOR~~ IN A MOTOR IN AN ELECTRIC OR PARTIALLY ELECTRIC MOTOR VEHICLE

Please replace paragraph beginning on page 1, lines 5, and ending on page 1, line 12 with the following amended paragraph:

This application is related to and shares disclosure with commonly assigned copending ~~prior~~ U.S. patent application serial number ________ 09/849,576 filed ________ 5/4/2001 by Vijay K. Garg et al., attorney docket number 50039-10010 (200-1095), entitled "Permanent Magnet Degradation Monitoring for Hybrid and Electric Vehicles," the disclosure of which prior application is hereby incorporated by reference, verbatim and with the same effect as through it were fully and completely set forth herein.

Please replace paragraph beginning on page 1, line 13, and ending on page 1, line 21 with the following amended paragraph:

Also, this application is related to and shares disclosure with commonly assigned copending U.S. patent application serial number ________ 09/682,533 filed ________ 9/17/2001 by Abbas Rafteri et al., attorney docket number 50039-10040 (200-1676), entitled "Adaptive Demagnetization Compensation for a Motor in an Electric or Partially Electric

Motor Vehicle," the disclosure of which prior application is hereby incorporated by reference, verbatim and with the same effect as through it were fully and completely set forth herein.

Please replace paragraph beginning on page 1, line 22, and ending on page 2, line 6 with the following amended paragraph:

Also, this application is related to and shares disclosure with commonly assigned copending U.S. patent application serial number ~~________~~ 09/682,534, filed ~~________~~ 9/17/2001 by Abbas Rafteri et al., attorney docket number 50039-10050 (201-0530), entitled "Adaptive Demagnetization Compensation for a Motor in an Electric or Partially Electric Motor Vehicle," the disclosure of which prior application is hereby incorporated by reference, verbatim and with the same effect as through it were fully and completely set forth herein.

Please replace paragraph beginning on page 2, line 7, and ending on page 2, line 15 with the following amended paragraph:

Also, this application is related to and shares disclosure with commonly assigned copending U.S. patent application serial number ~~________~~ 09/682,537, filed ~~________~~ 9/17/2001 by Abbas Rafteri et al., attorney docket number 50039-10060 (201-0531), entitled "Adaptive Demagnetization Compensation for a Motor in an Electric or Partially Electric Motor Vehicle," the disclosure of which prior application is hereby incorporated by reference, verbatim and with the same

effect as through it were fully and completely set forth herein.

Please replace paragraph beginning on page 2, line 19, and ending on page 2, line 23 with the following amended paragraph:

The present invention relates generally to hybrid electric vehicles (HEV) and electric vehicles, and specifically to identifying ~~faults due to~~ demagnetization of permanent magnets ~~magnet degradation~~ in motors/generators in hybrid electric and electric vehicles.

Please replace paragraph beginning on page 5, line 12, and ending on page 6, line 7 with the following amended paragraph:

U.S. Patent No. 5,650,706 issued to Yamada et al. ("Yamada") is directed to a control device for a salient pole type permanent magnet motor. The object of that device is to prevent torque from lowering due to demagnetization of the magnet. A magnetic flux of the permanent magnet is calculated or inferred by determining an electromotive force of the permanent magnet in accordance with a voltage and current supplied to the permanent magnet motor, a rotational speed of the motor, and an inductance of the permanent magnet motor.

This electromotive force is compared to a reference electromotive force representative of a fully magnetized permanent magnet. This process is complex and cumbersome. Direct detection of demagnetization is suggested in Yamada by using certain sensors, such as a Hall device or a magnetoresistance element. These direct detection methods suggested in Yamada are relatively expensive and impact serviceability due to location of a complex sensor in the motor housing. Also, demagnetization beyond a safety limit is not monitored and reported for safety-related actions. Furthermore, no specific ~~faults causing demagnetization~~ demagnetized magnets are identified for maintenance.

Please replace paragraph beginning on page 6, line 24, and ending on page 7, line 3 with the following amended paragraph:

Yet another object of the present invention is to provide adaptive strategies to compensate for permanent magnet ~~degradation~~ demagnetization, including protection of components, limited operation, and notification of permanent magnet ~~degradation~~ demagnetization to a user of the vehicle.

Please replace paragraph beginning on page 7, line 4, and ending on page 7, line 6 with the following amended paragraph:

Yet still another object of the present invention is to detect and identify ~~faulty components relating to permanent magnet degradation~~ demagnetized permanent magnets in a motor in a vehicle.

Please replace paragraph beginning on page 7, line 11, and ending on page 8, line 7 with the following amended paragraph:

In accordance with one aspect of the present invention, a device is provided for detecting ~~faults due to~~ permanent magnet ~~degradation~~ demagnetization in a motor in a vehicle. The device includes a voltage monitor that detects a permanent magnet induced voltage within the motor at a predetermined speed and no load condition. The voltage monitor is coupled to a processor that receives the permanent magnet induced voltage, as measured at the predetermined speed, and compares the permanent magnet induced voltage to a reference voltage that reflects the permanent magnet induced voltage for the motor with a fully magnetized permanent magnet. The processor determines a difference in the detected permanent magnet induced voltage and the reference voltage. The difference is analyzed to determine if a permanent magnet ~~component~~ is ~~faulty~~ demagnetized. In particular, the permanent magnet induced voltage is a function of the relative positions and

locations of the permanent magnets in the motor. This relationship is used to identify a ~~faulty~~ demagnetized magnet. In particular, the permanent magnets are configured such that a change in magnetic reluctance or magnetic strength is used to identify a ~~faulty~~ demagnetized magnet. A diagnostic code is set to alert others of the position of the failing magnet for replacement or other corrective action.

Please replace paragraph beginning on page 8, line 8, and ending on page 9, line 8 with the following amended paragraph:

In accordance with another aspect of the present invention, a method is provided for identifying ~~a component that is faulty and causing~~ demagnetization of a permanent magnet ~~degradation~~ in a motor of a vehicle. The method includes the step of detecting a first signal that is a function of magnetism of a plurality of permanent magnets in the permanent magnet motor. Then the first signal is compared with a reference signal that represents a function of magnetism of the plurality of magnets in the permanent magnet motor. The reference signal reflects a level of magnetization that is expected where the plurality of permanent magnets in the motor are fully magnetized. A difference between the first signal and the reference signal is analyzed to determine

a ~~faulty component~~ demagnetized permanent magnet that is likely causing the difference. In particular, the first signal and reference signal include points of synchronization that relate to the position of potentially ~~faulty components~~ demagnetized permanent magnets. More specifically, the points of synchronization are caused by a predetermined change in structure of the motor at a particular location relative to the location of the permanent magnets. This change in structure results in a change in motor reluctance or magnet strength that is reflected in the first signal and the reference signal. Hence, differences between the first signal and the reference signal are correlated to a position of a ~~faulty component~~ demagnetized permanent magnet. A device in accordance with the invention includes a processor that executes the method described above.

Please replace paragraph beginning on page 10, line 1, and ending on page 10, line 4 with the following amended paragraph:

FIG. 5 and FIG. 6 are graphs illustrating a method for detecting a ~~fault due to~~ demagnetization of a permanent magnet ~~magnetism degradation~~ in accordance with a preferred embodiment of the present invention.

Please replace paragraph beginning on page 11, line 13, and ending on page 12, line 11 with the following amended paragraph:

A vehicle system controller (VSC) 46 controls many components in this HEV configuration by connecting to each component's controller. An engine control unit (ECU) 48 connects to the engine 24 via a hardwire interface. The ECU 48 and VSC 46 can be housed in the same unit, but are preferably separate controllers. The VSC 46 communicates with the ECU 48, as well as a battery control unit (BCU) 50 and a transaxle management unit (TMU) 52 through a communication network, such as a controller area network (CAN) 54. The BCU 50 connects to the battery 36 via a hardwire interface. The TMU 52 controls the generator motor 30 and traction motor 38 via a hardwire interface. More specifically, TMU 52 includes a controller that executes a stored program to determine the torque of generator motor 30 and traction motor 38. Also, in accordance with the present invention, TMU 52 detects and stores an indication of the magnetization of permanent magnets in generator motor 30 and traction motor 38. In particular, a voltage sensor incorporated in generator motor 30 and a voltage sensor in traction motor 38 determine a voltage that is proportional to the magnetization of permanent magnets in

generator motor 30 and traction motor 38, as described below. Also, in accordance with the present invention, TMU 52 determines which ~~components~~ permanent magnets are likely ~~faulty~~ demagnetized due to changes in magnetization.

Please replace paragraph beginning on page 15, line 17, and ending on page 16, line 3 with the following amended paragraph:

In accordance with an aspect of the present invention, rotor 200 includes an indication, irregularity or notch 212 positioned in an area of the rotor iron near and adjacent to permanent magnets 208a. As discussed further below, notch 212 is used to generate a signal that has a point of synchronization that relates to the position/location of a particular one or more of permanent magnets 208a-d, in this case, magnet 208a. More specifically, notch 212 changes the motor reluctance or magnetic resistance, which results in a corresponding change in a voltage induced in sensor coil 210. Based on the point of synchronization, a failing or demagnetized ~~faulty~~ permanent magnet is identified.

Please replace paragraph beginning on page 16, line 14, and ending on page 17, line 6 with the following amended paragraph:

In accordance with an aspect of the present invention, permanent magnet set 218a includes a predetermined irregularity, protrusion 222, on one the permanent magnets in permanent magnet set 218a. Protrusion 222 is preferably an extension of a magnet of permanent magnet set 218a or an additional component of magnetic material. As discussed further below, protrusion 222 is used to change the magnetic strength of the magnet set 218a (as compared to 218b-d), which in turn generates a signal that has a point of synchronization that relates to the position of permanent magnet set 218a. Based on the point of synchronization, a demagnetized ~~failing or faulty~~ permanent magnet or set is identified. As an alternative to using additional magnetic material for protrusion 222, protrusion 222 may be non-magnetic material, such as brass. In this case, the protrusion causes an increase in motor rotor reluctance at the protrusion, which in turn generates a signal that has a point of synchronization that relates to the position of permanent magnet set 218a.

Please replace paragraph beginning on page 18, line 12, and ending on page 20, line 8 with the following amended paragraph:

After the permanent magnet induced voltage is detected, the permanent magnet induced voltage is compared to a reference voltage that reflects a permanent magnet induced voltage at no demagnetization and the same predetermined speed at which the permanent magnet induced voltage is detected. That is, the reference voltage is the value expected for the permanent magnet induced voltage if the permanent magnet is fully magnetized. Preferably, the reference voltage is stored in TMU 52. Any difference between the reference voltage and the detected permanent magnet induced voltage is used to determine an indication of the amount of ~~degradation~~ demagnetization of the permanent magnet. This indication is preferably stored in a non-volatile memory for further reference. Also, the indication of magnetic strength is compared to a first threshold to determine if the permanent magnet has reached a point of ~~degradation~~ demagnetization where additional precautions should be taken. Most preferably, if the magnetic strength is below a predetermined first threshold, an indication is made to a user of the vehicle, for example, through an audible or visual indication

that is transmitted via controller area network 54. Also, the current to the motor is limited to an amount that prevents damage to components of the vehicle and/or the TMU 52 is calibrated to more accurately drive the inverter to force the motor to provide the torque required. Most preferably, the first threshold is chosen such that at least limited operation of the vehicle is possible. During a period of continued limited operation, permanent magnet ~~degradation~~ demagnetization along with other motor parameters, such as temperature, are monitored. The results from further monitoring are compared to a second threshold. This threshold is alternatively a level of magnetism, a certain temperature, or another monitored parameter. If the second threshold is not met, then monitoring continues. If the second threshold is met, then subsequent motor operation is suspended and a user of the vehicle is warned with an audible or visual indicator. Where another source of motive power is available, operation of the wheels of the vehicle is switched to that motive source. For example, in the preferred embodiment of FIG. 1, if the generator motor 30 is made inoperable due to permanent magnet ~~degradation~~ demagnetization, then wheels 42 are operated under control of traction motor 38. Alternatively, if traction motor 38 is made inoperable due to permanent magnet ~~degradation~~ demagnetization, then wheels 42

are operated under control of generator motor 30 and engine 24. Most preferably, if the traction motor 38 is inoperable, generator motor 30 is first used to bring wheels 42 to a certain speed, and then engine 24 is activated to provide additional motive force via a smooth transition.

Please replace paragraph beginning on page 20, line 9, and ending on page 20, line 16 with the following amended paragraph:

Once maintenance of the vehicle occurs, a ~~faulty component, such as a faulty~~ demagnetized permanent magnet or magnet set, is identified for replacement. In particular, a point of synchronization in a function of permanent magnet strength is compared to a reference function of permanent magnet strength. Differences between a detected function and the reference function are used to locate a ~~faulty~~ demagnetized magnet in a manner described below with respect to FIG. 5 and FIG. 6.

Please replace paragraph beginning on page 21, line 23, and ending on page 22, line 16 with the following amended paragraph:

FIG. 6 shows a curve 310 of an exemplary detected function of magnet demagnetization in accordance with an aspect of the present invention. Curve 310 illustrates a voltage detected as a result of magnet ~~degradation~~ demagnetization of one of permanent magnets 208a-d of FIG. 3. An analysis of curve 310 is preferably used to determine which permanent magnet is contributing to demagnetization so that that magnet may be replaced. Notably, curve 310 has points of synchronization 306. The points of synchronization are used to delineate a signal for comparison with a reference signal. Deviations between the comparison are indicative of a ~~faulty~~ demagnetized permanent magnet component. Notably, peak 304b is substantially degraded in curve 310. Since peak 304b relates to magnet 208b, curve 310 indicates ~~degradation~~ demagnetization of magnet 208b. A comparison of curve 310 and curve 302 readily identifies the ~~degradation~~ demagnetization in curve 310, which reflects that curve 310 indicates magnet 208b is ~~faulty~~ demagnetized. Preferably, a diagnostic code in the vehicle is set to indicate that magnet 208b is ~~faulty~~ demagnetized.

Please replace paragraph beginning on page 23, line 9, and ending on page 23, line 15 with the following amended paragraph:

As discussed above, the present invention provides a simple and effective method of determining the state of magnetism of a permanent magnet in a motor of a vehicle. Advantageously, a signal representative of the state of magnetism is compared with a previously stored signal representative of the fully magnetized state to identify likely ~~faulty components~~ demagnetized permanent magnets.